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MULTI-TASK TIME-SHARING REQUIREMENTS

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Ohio State University

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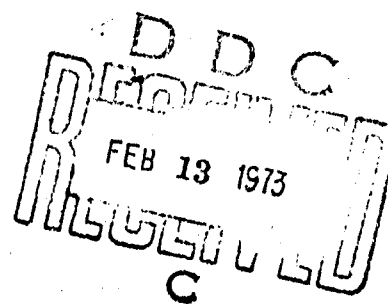
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13. ABSTRACT

Ten laboratory experiments are reported on dual-task performance. A continuous tracking task and a discrete choice reaction time task were used as representative of the kinds of information processing required of the aircraft pilot. The research dealt with three major concerns: (1) a demonstration of the time-sharing effect (poorer performance under dual than under single-task conditions) and an examination of the influence of auditory noise on the time-sharing effect, (2) localizing the time-sharing effect in an input, an output or in a central stage of human information processing, and (3) the influence of variations in the tracking task (input complexity, S-R compatibility), variations in augmented feedback across tasks, and the influence of auditory noise on dual-task performance.

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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FOREWORD

This study was initiated by the Human Engineering Division of the Aero-
space Medical Research Laboratory. The research was conducted by the
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Research Foundation, under Air Force Contract F33615-69-C-1663. George
E. Briggs, PhD, was the principal investigator for Ohio State University.
Donald A. Topmiller, PhD, Chief of the Systems Effectiveness Branch,
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The research sponsored by this contract was started in June 1969 and
was completed in July 1971.

Those personnel directly involved in the planning and conducting of
each experiment are listed with the appropriate experiment.

This technical report has been reviewed and is approved.

JULIEN M. CHRISTENSEN, PhD
Director
Human Engineering Division
Aerospace Medical Research Laboratory

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SECTION I

INTRODUCTION

These laboratory experiments were designed to investigate how the human
operator carries out two concurrent tasks. The need "to do two things
at once" is a fairly common requirement in vehicular control situations
as when the pilot controls his aircraft while engaged in radio communi-
cation with an air control facility or while carrying out navigation
and/or system management calculations. Thus the operator must time share
his capacity to process task-relevant information (and thereby generate
appropriate responses) between the two tasks.

Two tasks were selected for use in this research program: a continuous
(tracking) task and a discrete (choice-reaction-time) task. The tracking
task was selected as being representative of the information processing
demands placed on the human operator in controlling his vehicle. The
discrete task utilized auditory inputs to the operator and required that
he classify the several input items into a small number of output cate-
gories; thus this task was felt to be representative of those real-life
situations wherein the operator has only a few possible courses of action,
and so he must select a particular course or output to each of several
possible inputs, the number of different inputs being greater than the
number of output states.

Section III of this report concerns research (a) which sought to demon-
strate the presence of a time-sharing effect, i.e. poorer performance
when both tasks were required concurrently than when only the single dis-
crete task was required, and (b) which sought to determine the influence
of auditory noise in the discrete task on both dual- and single- task
performance. Section IV provides results from research which was con-
cerned with localizing the time-sharing effect at an input, an output,
or a central level of human information processing. Finally, in section
V research is reported on dual-task performance when the characteristics
of the tracking task were varied, the experimental conditions of sections
III and IV having involved systematic variations in only the discrete,
reaction-time task.

GENERAL METHODOLOGY

The tracking task confronted the human operator with a one-dimensional pursuit display, a spring-centered control device by which he attempted to bring the displayed cursor in coincidence with the displayed target, and rate control dynamics. With rate control dynamics one finds a linear relationship between amplitude of control device deflection from its center or null position and the rate at which the cursor moves on the visual display. In this research, cursor speed was approximately 1.06 mm per second for each degree of deflection of the control device. Except for that research in which it was necessary to provide a low degree of stimulus-response compatibility (see section V), the control/display directional relationship was such that the display cursor moved in the same direction as did the control device when deflected. The display and the control were mounted in the same plane: parallel to the operator's frontal plane.

The tracking display was provided via a 5-inch cathode ray tube with a time-sharing switch which permitted the separate painting of two verticle lines. Each line was 20 mm in length. The top line served as the target element and it was driven by a signal generator. The bottom line served as the cursor, and there was a 2 mm overlap of the two indicators.

The discrete choice-reaction-time task was the fixed-set version described by Sternberg (1966). In that task the observer is read a set of 1, 2 or 4 items to be held in memory for a block of trials. These items are called the positive set and they define the memory load present for a block of trials. Then the observer hears a series of test stimuli, and to each he makes one of two responses: "yes" that test stimulus matches one in the memorized (positive) set or "no" there is no match (the test stimulus is a member of the negative set). Typically, one finds a linear relationship between reaction time (RT) and central processing uncertainty (H_c):

$$RT = a + b(H_c) \tag{1}$$

where H_c is a Shannon (1948) expression which is determined primarily by memory load (see Briggs and Swanson, 1970). The calculation of H_c is discussed in the Appendix herein.

The Sternberg task was selected because it has been used quite successfully to provide analytical insights on how the human operator processes information (see Sternberg, 1969a, 1971; and Briggs and Swanson, 1970). These analytic insights are based on recent interpretations of the intercept and slope constants of the preceding statement of additivity in reaction time: the intercept constant $\underline{a}$ reflects the time required to carry out the stimulus encoding, sampling and preprocessing functions of

the initial or input stage of human information processing plus the time
to decode a response in the output stage; the slope b represents the time
per central test to carry out the stimulus classification functions at a
central processing stage (between the encoding and decoding stages).

Thus if an independent variable influences the intercept constant a but
not the slope constant b, then that variable has affected either the
encoding or the decoding stage, while an independent variable which influ-
ences the central processing stage will reveal that effect on the slope
constant b. The several experiments reported in section IV were concerned
with whether the a or the b constant would be influenced by the dual task
or time sharing requirement. In this way one can localize the time-sharing
effect in one of the three sequential stages of human information process-
ing. In section V the independent variables were applied to the tracking
task, and the Sternberg task served as a mirror to reflect which of the
stages of human information processing were influenced most by such
variables.

A reaction time clock began with the onset of an auditory stimulus (a
word or a letter, depending upon the experiment) which was played from
a tape recorder. That clock was stopped with a switch closure by the
human operator who wore headphones and who used the left hand index and
middle fingers to close the "match" and "no-match" switches. The clock
was accurate to a millisecond. The tape recorder provided the positive
set at the beginning of a block of trials as well as the individual test
stimuli. A block consisted of 24 auditory test stimuli, half of which
matched while half did not match a member of the positive (memorized)
set. The test stimuli occurred every 4 seconds (when letters of the
alphabet were utilized) or every 6 seconds (when words were used as
stimuli). There were two and a half blocks of trials per memory-load-
condition in each daily session. Typically a given operator spent 20
to 25 minutes per daily session in an experiment, and did so for five
such sessions. Pay was $1.25 per session, an effective rate of about
$2.50 per hour.

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THE TIME-SHARING EFFECT AS INDICATED BY A
CHOICE REACTION TIME TASK

EXPERIMENT 1: THE EFFECTS OF STIMULUS DISCRIMINABILITY AND AUDITORY
NOISE ON TIME SHARING.
J. Lyons and G. E. Briggs.

In this first of three experiments there were eight experimental conditions defined by the orthogonal combination of (a) the single discrete Sternberg task versus the dual tasks (the discrete task concurrent with the continuous tracking task), (b) low versus high stimulus discriminability for the discrete task stimuli, and (c) the presence (at 87 dB) of auditory noise in the discrete task versus a noise-free condition. Stimulus discriminability was a between-subject (operator) variable while the other two independent variables were within-subjects, as was memory load (M) which occurred at three levels: M = 1, 2 or 4 words.

In this experiment there was an equal number of stimuli in the positive and negative set for each memory load condition. The words are listed in table 1. Thus, a particular subject might have the word "lively" in his positive set under the M = 1 condition. If he was assigned to the low-discriminability group his negative set consisted of the single word "likely" while if he was in the high-discriminability group the single negative-set word under the M = 1 condition was "lining". Under the M = 2 condition a subject in the high-discriminability group might have the words "region" and "bundle" in his positive set, in which case the negative set consisted of the words "reduce" and "budget"; however, a subject in the low-discriminability group would have the negative set words "reason" and "bubble" for the same positive-set items. Memory load was set for a block of 24 trials (test stimulus presentations),

Table 1. Stimulus Words Used in Experiment 1

Low Discriminability		High Discriminability	
Positive Set	Negative Set	Positive Set	Negative Set
Bundle	Bubble	Bundle	Budget
Defend	Descend	Defend	Depart
Evil	Eagle	Evil	Eastern
Fatal	Fable	Fatal	Failure
Lively	Likely	Lively	Lining
Quarrel	Coral	Quarrel	Column
Region	Reason	Region	Reduce

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and thus the above subject under the M = 1 high-discriminability condition heard the words "lively" and "lining" in random orde: for 24 presentations and made a "match" or a "no-match" response to the occurrence of each word.

The word stimuli were presented every 6 seconds over headphones. Under noise listening conditions the subjec. heard the test stimuli imbedded in 87 dB of noise. The noise was obtained by filtering a white noise source to the spectrum of the ambient noise present at the ear of a F-105D pilot in flight when wearing a helmet fitted with an H-154/AIC headset. In noise-free listening condition, the subject heard only background hum (at approximately 45 dB) in the headphone - intercom system.

The tracking task was as described above. It utilized the pursuit display and a band-limited random input. The band pass limits on the input signal were 0.02 to 0.04 Hz with 24 dB per octave attenuation at the band limits. The integral of the absolute value of tracking error was recorded across the final 2 minutes of each $2\frac{1}{2}$-minute trial.

Performance on the discrete task was measured by cumulating the reaction times to each of the 24 test stimuli in each block (which corresponded to the total duration of a tracking trial). There were two and one-half blocks under each memory load condition per daily session, and there were five such sessions for each subject. Appropriate counterbalancing of order of conditions was accomplished across subjects. There were 12 subjects per group (stimulus discriminability level).

RESULTS AND DISCUSSION

The results are summarized in table 2. The reaction times are listed in seconds while tracking performance is in arbitrary voltage units.

Table 2. Average Reaction Time (in Secon:s) from the Discrete Task and Average Integrated Absolute Error (in Volts) from the ᵀracking Task of Experiment 1.

| Task | Noise | Discriminability | | | | | |
| | | Low | | | High | | |
		M1	M2	M4	M1	M2	M4
Single	Present	0.657	0.875	0.963	0.657	0.828	0.879
	Absent	.571	.712	.743	.540	.711	.765
Dual	Present	.950 (333V)	1.024 (302V)	1.114 (330V)	.877 (436V)	.987 (446V)	1.060 (390V)
	Absent	.947 (291V)	.996 (313V)	1.001 (305V)	.819 (362V)	.962 (320V)	1.085 (374V)

Note that average reaction times were substantially longer under dual-task than under single-task conditions and that discriminability had no consistent effect on reaction time. Note also the slightly longer average reaction times when auditory noise was present then when no noise was present to interfere with the discrete task stimuli. The latter result replicates the basic result noted by Sternberg (1967) with visual noise.

The results of an analysis of variance applied to the reaction time data support the observations from table 2. Of particular importance from the analysis was the finding that no interaction was statistically significant, although there does appear to be an interaction evident: In table 2 the dual-task/low-discriminability data for both noise conditions involves much less of a difference between memory loads $M = 1$ and $M = 4$ than do any of the other sets of conditions. This is more apparent in table 3 where the results are listed of least square fits of equation 1 to the data. Within each pair of noise conditions, parallel straight lines were fit to the data. Except for the dual-task/low-discriminability data, the slope constant $\underline{b}$ is quite similar for each condition, and the intercept constant $\underline{a}$ shows the consistent noise effect.

Table 3. Least Square Fits of Equation 1 to the Reaction Time Data of Table 2.

Task	Discriminability	Noise	$RT = a + b(H_c)$
Single	Low	Present	$RT = 0.593 + 0.120(H_c)$
	Low	Absent	$RT = 0.436 + 0.120(H_c)$
	High	Present	$RT = 0.565 + 0.112(H_c)$
	High	Absent	$RT = 0.449 + 0.112(H_c)$
Dual	Low	Present	$RT = 0.920 + 0.054(H_c)$
	Low	Absent	$RT = 0.872 + 0.054(H_c)$
	High	Present	$RT = 0.750 + 0.112(H_c)$
	High	Absent	$RT = 0.731 + 0.112(H_c)$

A time-sharing effect is revealed by the reaction-time data: the intercept constants are uniformly and substantially lower under single- than under dual-task conditions. According to the common interpretation of equation 1, those variables which influence the intercept constant $\underline{a}$ (but not $\underline{b}$) have their influence either in the initial encoding stage or the output stage of human information processing. The present experiment does not permit one to be more precise in localizing the time-sharing effect, but the matter will be considered in section IV.

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The present data indicate that audi'ory noise has an effect similar to that of visual noise in the Sternberg task: the intercept a, not the slope constant b, is affected by this variable. We may echo Sternberg (1967) in suggesting that the longer values of a under noise conditions arise from the time required for the observer to filter out signal from noise in the initial encoding stage. Once this reasonably noise-free representation has been encoded, the comparison of the representation with memorial features of potential stimuli can occur at a rate independent of the amount of noise originally present.

The reciprocal of the slope constants of table 3 provides estimates of the speed of central processing. For the moment, ignoring the b value of 54 msec, the average value of b was 115 msec, the reciprocal being 8.7 bits per second as the estimate of central processing speed.

The dual-task/low-discriminability condition was the most demanding of the experimental conditions used, and yet table 2 shows that tracking performance was superior under this condition to that when the dual-task condition was paired with the easier high-discriminability condition. Note that the higher the tracking (absolute error) score, the poorer the tracking performance. This is consistent with the remarks provided by the subjects who served under the low-discriminability conditions: they indicated that it was necessary "to pay more attention to the difficult tracking task" under the low-discriminability condition. This accounts for the better tracking performance and could account too for the very low value of 54 msec found for the slope constant b under this same experimental condition (see table 3): apparently if one "attends less" to the discrete task, this results in an increase in average reaction time, and here that gave rise to a higher intercept a and a lower slope constant b of equation 1.

The foregoing information suggests that the present subjects in the dual task/low discriminability condition not only delayed encoding and/or decoding but speeded up their central processing of the discrete task information. Probably the latter was achieved by conducting fewer or less complete tests on the encoded stimulus representations.

In any case, experiment 2 was conducted to see if the low slope constant in table 3 was an artifact of how the present subjects "divided" their attention between the discrete and the tracking task in experiment 1 under the low-discriminability condition.

From experiment 1, the Sternberg task appears to provide a sensitive indicant of the time-sharing effect.

EXPERIMENT 2: AUDITORY NOISE AND TIME SHARING
                J. Lyons, R. P. Fisher, and G. E. Briggs.

As previously indicated, the slope constants listed in table 3 for the dual-task low-discriminability condition are suspiciously low while the intercepts are rather high. This was suspected to be due to the

relatively unskilled level of the subjects, and several subjects found it necessary "to attend more to the difficult tracking task" than to the discrete reaction-time task. Thus when confronted with the most demanding set of conditions (low discriminability plus dual task requirements), the subjects apparently devoted more attention and information processing capacity to that which appeared to be the more difficult aspect of the situation, the tracking task. This produced artifactually high reaction times which resulted in a strange combination of high intercepts but low slope constants as in table 3.

The present experiment was conducted with three subjects who had had considerable tracking experience prior to service in this experiment. Three the the eight conditions from experiment 1 were utilized: (1) the discrete reaction time task under the no-noise condition, (2) the dual tasks under no-noise, and (3) the dual tasks under auditory noise. Only memory loads of M = 1 and M = 4 were used, and only the low-discriminability word lists were employed. All other aspects of the experimental situation were as they had been in experiment 1.

RESULTS

The results in terms of average reaction times are listed in table 4. Also listed in the table are fits of the basic RT-H_c equation. The latter were fit as parallel lines since an analysis of variance revealed no significant interaction of memory load by conditions ($F < 1.0$). The conditions differ significantly ($F = 12.18$, df $= 2/48$, $p < .01$); thus the slope constant of 113 msec is significant, as are the differences among the three intercept constants.

As expected, the slope constant from experiment 2 approximates quite nicely those found earlier in experiment 1 (see table 3). Therefore, we may compare the several intercept constants from tables 3 and 4 to determine the size of the experimental effects. These constants are listed

Table 4. The Results of Experiment 2 (in Seconds).

Task	Noise	M1	M4	RT = a + b (H_c)
Single	No Noise	0.435	0.610	RT = 0.296 + 0.113(H_c)
Dual	Noise	0.889	1.155	RT = 0.795 + 0.113(H_c)
	No Noise	0.757	0.996	RT = 0.650 + 0.113(H_c)

under the appropriate headings in table 5. Note that in experiment 2 the single-task, noise condition was not run. An estimate can be made of that intercept value: First, note that the intercept under the single-task, no-noise condition of experiment 2 (296 msec) was 140 msec, less than that obtained in experiment 1 under comparable conditions (436 msec). By using a 140-msec correction to reduce the intercept

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actually found in experiment 1 under the single-task, noise-present
condition (593 msec), one obtains the 453 msec entry in table 5.

Table 5. Intercept Constants from Experiments 1 and 2 (in Seconds).

Task	Low Discriminability		High Discriminability	
	Noise	No Noise	Noise	No Noise
Dual	0.795	0.650	0.750	0.731
Single	(0.453)*	0.296	0.565	0.449
Time-sharing Effect	0.342	0.354	0.195	0.282

*Estimated, see text.

The third row of table 5 is of special interest: this is the differ-
ence between the entries in the first two rows; thus, the results in
the third row are indices reflecting the amount of the time-sharing
effect under the discriminability and under the noise conditions. Note
that a greater time-sharing effect occurred under the low-discriminabil-
ity condition than under the high-discriminability condition. Further,
while there seems to be less of a time-sharing effect under the noise
than under the no-noise condition of the high-discriminability condi-
tion, this is only apparent, not real, as there was no statistical
significance to any interaction in experiment 1.

EXPERIMENT 3:   LOCUS OF DISCRIMINABILITY IN AUDITORY MESSAGES.
                J. Lyons, R. F. Fisher, and G. E. Briggs

Another aspect of experiment 1 appeared worthy of additional attention:
Under the single-task condition in table 3, the intercept constant for
the noise-present/low-discriminability condition is only 28 msec,
greater than that for the noise-present/high-discriminability condition
(593 and 565 msec, respectively); likewise the low- and the high-
discriminability, no-noise conditions provided similar intercepts (436
and 449 msec, respectively).

Table 1 shows that the high-discriminability words differed in terms of
both the second (vowel) and third (consonant) phoneme sounds while the
low-discriminability words differed only on the second or vowel phoneme
sound. The fact that the intercepts of equation 1 were so similar for
the two discriminability conditions suggests that the subjects responded
in both cases to the first distinctive feature of the test stimuli: the
vowel sound. The fact that the high-discriminability stimuli differed
also in terms of the third or consonant phoneme sound apparently did not
affect the speed of response. The present experiment was designed to
explore this matter further.

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METHOD

Only the single, discrete-reaction time task was utilized; therefore, the results do not bear on questions of time sharing. Further, the negative-set stimuli were expanded in number. In experiments 1 and 2, there was a single negative-set word for each positive set word. In the present experiment, there were six negative-set words for each positive set word. Now, there were three discriminability conditions utilized: in the two low-discriminability conditions, one set of six negative-set words differed from their positive-set item only in terms of the middle or vowel phoneme sound (fill versus fall, fail, fool, file, fuel or full) while another set differed only in terms of the final consonant sound (fill versus fish, fifth, fix, film, fit or fist). For the high-discriminability condition, a positive-set word differed from its six negative-set words both in the middle (vowel) and terminal (consonant) phoneme sound (fill versus fight, four, fan, fire, food or fact).

There were separate groups of 14 subjects each run under these 3 discriminability conditions. In each group there were memory loads of $M = 1$, 2 and 4 words. A truly fixed set procedure was used, see Appendix, instead of the temporarily fixed set procedure of experiments 1 and 2. Each subject performed under both the no-noise and the auditory-noise conditions as used in experiments 1 and 2.

RESULTS

The average reaction times are listed in table 6 along with parallel fits (within discriminability conditions) of equation 1. As in experiment 1, performance was significantly faster under no-noise than under the noise condition. Further, memory load was statistically significant

Table 6. The Reaction Time Results of Experiment 3 (in Seconds).

Discriminability*	Noise	M1	M2	M4	$RT = a + b(H_c)$
Low (V)	Present	0.562	0.655	0.704	$RT = 0.451 + 0.126(H_c)$
Low (V)	Absent	0.512	0.584	0.623	$RT = 0.384 + 0.126(H_c)$
Low (C)	Present	0.668	0.743	0.807	$RT = 0.554 + 0.124(H_c)$
Low (C)	Absent	0.621	0.662	0.730	$RT = 0.486 + 0.124(H_c)$
High (VC)	Present	0.564	0.652	0.681	$RT = 0.466 + 0.111(H_c)$
High (VC)	Absent	0.503	0.557	0.609	$RT = 0.390 + 0.111(H_c)$

*V: middle phoneme or vowel sound difference
 C: terminal phoneme or consonant sound difference

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as was the difference between the Low C conditions and the Low V and High VC conditions. The latter two sets of conditions did not differ at $p < .05$.

The above results confirm rather well the hypothesis developed in experiment 1. The intercepts a of equation 1 are almost identical (for comparable noise levels) under conditions Low V and High VC (451 vs. 466 and 384 vs. 390 msec) while the Low C intercepts are almost 100 msec longer than those from the High VC condition (554 vs. 466 and 486 vs. 390 msec). It follows that a subject in the high-discriminability condition based his classification of test stimuli into either a positive-set or a negative-set category by reference to the first distinctive feature of those stimuli. The additional distinctive feature in the High VC condition did not speed the response. Compared to the other conditions, the subjects in the Low C condition apparently had to wait about 100 msec before processing their test stimuli.

CONCLUSIONS

1. Although the human operator can "do two things at once," his performance under such dual-task conditions is inferior to that under single-task conditions. Where practicable, structuring a work schedule for alternation among different aspects of a total task would be preferable to scheduling concurrent activities.

2. For a discrete task requiring manual responses to auditory stimuli, the time-sharing effect (performance deficit) appears to be greater when the stimuli are of low discriminability one from another than when they are easily distinguishable. However, the time-sharing effect is comparable when one listens for the stimuli through auditory noise as when one operates in a noise-free environment. Of course overall performance is worse under noise, but such a result holds equally for single- and dual-task situations (thus an equal time-sharing effect). It follows that to reduce the time-sharing effect one is advised to develop vocabularies of easily distinguishable words. Cleaning up the noise in a listening situation will improve performance, not the time-sharing effect; thus, time sharing presumably is more a matter of stimulus distinctiveness than it is a matter of discriminating signal from noise.

SECTION IV

ON THE LOCUS OF THE TIME-SHARING EFFECT

The four experiments reported in this section were concerned with <u>where</u>, in a four-stage model of human information processing, the time-sharing effect has its locus. The model is that described by Smith (1968) and, as applied to the Sternberg (1966) discrete reaction time task, it is as follows: In Stage 1 a test stimulus is encoded into a short-term store, stimulus information is scanned from that store, and the sampled information is held in a buffer memory ready for use in the next stage. In Stage 2 the representation of the test stimulus is tested against features of the positive-set items and the negative set as a class which have been retrieved from long-term memory to determine whether the input is a positive- or a negative-set stimulus. Stage 3 involves decoding (selecting) a response to express the outcome of Stage 2. Stage 4 consists of response execution.

Following the lead of Sternberg (1969) we will consider that a variable which influences the intercept constant a of equation 1

$$RT = a + b\,(H_c) \tag{1}$$

has its effect in either Stage 1 or Stage 3 of the Smith (1968) model while a variable that influences the slope constant b of equation 1 has its effect on Stage 2.

Therefore we can use the Sternberg task as one of two tasks in a time-sharing situation and compare the influence of an independent variable on equation 1 with that when only the Sternberg task is experienced. It should be possible to localize the time-sharing effect by finding an interaction between single- versus dual-task conditions and a variable which selectively affects the intercept or the slope constant of equation 1.

EXPERIMENT 4: AN INITIAL STUDY TO LOCALIZE THE TIME SHARING EFFECT. G. L. Peters and G. E. Briggs.

This experiment utilized the same methodology as that in experiments 1 and 2 (see Section I). Because of the apparent uncertainty of knowing when the human operator begins to process words as test stimuli in the discrete task, see experiment 3, letters of the alphabet rather than words were employed. Given this rather significant change in the discrete task, we decided to conduct an initial study with the straightforward purpose of seeing if the time-sharing effect could be localized in Stage 2 or central processing of the Smith (1968) model of human information processing. From experiment 2 one would predict that the time-sharing effect in the present study would influence the intercept, not the slope constant of equation 1; thus it would be localized in Stage 1 or 3, not in Stage 2 or the model.

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METHOD

The letters A, B, F, G, I, L, N, O, Q, R, U, and Y served as stimuli. These were chosen from the entire alphabet as being minimally confusable acoustically (Conrad, 1964). The subject wore headphones, over which test stimuli were read every 4 seconds during a block of trials. There were 24 stimuli (trials) per block and half were from the subject's positive set while the other half were from the negative set. To each test stimulus the subject emitted a match or a no-match response by pressing one of two buttons with the index or middle finger of the left hand. There were three blocks of trials under each of three memory load levels (M = 1, 2 or 4 letters in the positive set) per day, and there were one practice and three daily experimental sessions.

There were two groups of subjects with 12 subjects per group: the single-task group performed only the discrete Sternberg task while the dual-task group performed both the discrete task and the same tracking task as had been used in experiments 1 and 2. The subjects were reimbursed at $1.25 per session (approximately 25 minutes of time), and none had served in the previous research.

RESULTS

The group averages for each memory load level are listed in table 7, along with least square fits of equation 1 to the data of the two groups. The fits of equation 1 were made in parallel to the two sets of data because an analysis of variance indicated no significant interaction between groups and memory load. Groups and memory load each were statistically significant as main effects at $p < .001$. Thus, there was a significant time-sharing effect, and the slope of 76 msec per bit of central processing uncertainty is significant.

Table 7. Average Reaction Times (in Seconds) and Fits of Equation 1 to the Data of Experiment 4.

| Group | Memory Load | | | $RT = a + b\,(H_c)$ |
	M1	M2	M4	
Single Task	0.406	0.487	0.575	$RT = 0.338 + 0.076(H_c)$
Dual Task	0.568	0.638	0.702	$RT = 0.484 + 0.076(H_c)$

Table 7 shows that the dual-task group required about 146 msec longer, on the average, to respond then did the single-task group. Since this was an intercept effect, it follows that the time-sharing effect is not localized in Stage 2 of the Smith (1968) model of human information processing. Apparently it is an input (Stage 1) or an output (Stage 3)

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effect. Experiments 5, 6, and 7, which follow, were designed to local-
ize the time-sharing effect more specifically.

EXPERIMENT 5: SPEED VERSUS ACCURACY AS A VARIABLE IN A TIME-SHARING TASK.
R. P. Fisher, G. L. Peters, and G. E. Briggs.

Research by Swanson and Briggs (1969) indicates that stage 1 is the locus
of the speed/accuracy tradeoff in human information processing: If one
group is encouraged to make about 15-percent errors, say, and another
group is encouraged to slow their reaction times sufficiently to make
less than 5-percent errors, the fits of equation 1 will show signifi-
cantly different intercept constants but comparable slope constants for
the two groups. Therefore, if one makes the speed versus accuracy vari-
able orthogonal to the single- versus dual-task variable, one should
observe an interaction of the two variables if the time-sharing effect
is localized in the input stage, Stage 1 of the Smith (1968) model. The
present experiment utilized this design.

METHOD

There were four groups of subjects with six subjects per group. Two of
the groups experienced only the single (discrete) task while the other
two groups encountered the dual (discrete plus tracking) tasks. One of
each pair of groups was instructed to provide fast responses while the
other group in each pair received accuracy instructions. The instruc-
tions were implemented by a bonus system which rewarded the subject on
the joint basis of speed and accuracy criteria. See Swanson and Briggs
(1969) for a description of the bonus system.

Each subject served for five daily sessions. The first session was con-
sidered practice and those data were not analyzed. Sessions 2 and 4
were used to establish speed criterion times for the bonus system used
on Sessions 3 and 5. Only the data from Sessions 3 and 5 were utilized
in the analysis reported herein. The criterion times were set to elicit
about 5-percent errors from the accuracy groups and about 15-percent
errors from the speed groups. In all other respects the methodology was
identical to that in experiment 4.

RESULTS

An analysis of variance was performed on the reaction-time data of all
four groups. Both memory load (M = 1, 2 and 4) and accuracy level
(5 versus 15 percent errors) were statistically significant (p< .01);
however, the interaction of these two variables was not significant
(p> .05). Table 8 provides the group average reaction times and paral-
lel least square fits of equation 1.

From the results of the analysis of variance and from the fits of equa-
tion 1 in table 8, there was no interaction of the time sharing variable
and the speed/accuracy variable. These two variables, then, influence
different stages (or different components within a stage) of human

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information processing. Since the speed/accuracy variable is localized
in Stage 1, these results apparently exclude Stage 1 (or at least that
part influenced by the speed/accuracy variable) as the locus of the
time-sharing effect.

Table 8. Average Reaction Times (in Seconds) and Best Fits
of Equation 1 to the Data of Experiment 5.

| Task Condition | Speed vs. Accuracy | Memory Load | | | $RT = a + b(H_c)$ |
		M1	M2	M4	
Single	Accuracy	0.394	0.455	0.542	$RT = 0.338 + 0.063(H_c)$
Single	Speed	0.364	0.418	0.488	$RT = 0.298 + 0.063(H_c)$
Dual	Accuracy	0.430	0.481	0.551	$RT = 0.362 + 0.063(H_c)$
Dual	Speed	0.404	0.431	0.513	$RT = 0.324 + 0.063(H_c)$

EXPERIMENT 6: RESPONSE LOAD AS A VARIABLE IN A TIME-SHARING TASK.
G. L. Peters, R. P. Fisher, and G. E. Briggs.

Having failed to localize the time-sharing effect in the encoding stage,
see experiment 5, we decided next to determine if the effect could be
localized in the decoding stage (Stage 3) of the Smith (1968) model.
This seemed unlikely on an a priori basis since it is known that one can
in fact "do two things at once" as in walking and talking simultaneously;
thus it seems less likely that an output function would be the locus of
the time-sharing effect than it is that an input function would be the
"bottleneck."

Nevertheless a variable was selected which from an earlier study by
Briggs and Swanson (1970) was believed to influence the response decoding
function or Stage 3. This variable, response load, was set at two levels
$R = 2$ and $R = 4$. Under the $R = 2$ level, the subject encounters the same
Sternberg task conditions as in experiments 1 through 5: to each test
stimulus, he selects and emits one of two responses - match or no match.
Under the $R = 4$ condition, the subject must select one out of four pos-
sible responses to each test stimulus: one pair of responses involved
a match and a no-match response to a stimulus read by a male voice while
the other pair of responses involved a match and a no-match response to
stimuli read in a female voice.

In addition to response load, memory load (three levels) and a single-
versus dual-task conditions were present in this experiment.

METHOD

The same materials and procedures were used here as in experiment 5
except that the response load variable was substituted from the speed/
accuracy variable. To use the response load variable, all audio tapes

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used in experiment 5 were rerecorded with half the test stimuli being read by a female and half read by a male assistant. The sequence of "male" and "female" test stimuli was randomized within each block of trials.

Each subject heard the same audio tapes regardless of group assignment. The two groups who worked under the R = 2 condition made only one of two possible responses (button presses) to each test stimulus, however, while the R = 4 groups emitted one of four possible responses. Under the R = 2 condition, sex of the speaker was irrelevant and could be ignored; whereas, it could not be ignored under the R = 4 condition since it served as a basis for part of the response selection (decoding) process.

Another set of 24 subjects served in experiment 6. There were six subjects in each of the four groups formed by the two levels of response load and the single- versus dual-task conditions.

RESULTS

An analysis of variance was applied to the data of the four groups. All three main effects were statistically significant (response load, memory load and single versus dual task) and, surprisingly, the interaction memory load by response load by single versus dual task was significart at $p < .05$. This suggested that we had been able to localize the time-sharing effect. However the locus apparently was in Stage 2 (since the interaction involved memory load, the variable known to influence the central processing stage), and this was in conflict with most of the previous data in this series. Further, Briggs and Swanson (1970) did not find an interaction of response load and memory, and so the present data seem in conflict with numerous previous studies. As such, one must view the results of experiment 6 with considerable skepticism.

Table 9 provides the average reaction times and parallel fits of equation 1 to the data. Parallel fits were carried out despite the above interaction as it simply was beyond belief that response load can interact with memory load. From table 9 there is a substantially greater

Table 9. Average Reaction Times (in Seconds) and Parallel
Fits of Equation 1 to the Data of Experiment 6.

Task Condition	Response Load	Memory Load			RT = a + b(H$_c$)
		M1	M2	M4	
Single	R = 2	0.486	0.546	0.657	RT = 0.439 + 0.062(H$_c$)
Single	R = 4	0.637	0.676	0.756	RT = 0.566 + 0.062(H$_c$)
Dual	R = 2	0.692	0.740	0.791	RT = 0.617 + 0.062(H$_c$)
Dual	R = 4	0.747	0.794	0.856	RT = 0.675 + 0.062(H$_c$)

difference between the intercepts under the single-task than under the dual-task conditions (differences of 127 and 58 msec, respectively). Following the lead of Briggs and Swanson (1970) straight line functions were fit to the intercept values in table 9, and the result for the dual-task intercepts $\underline{a}$ is

$$a = 0.559 + 0.029(R)$$

where R is response load. For the single-task data

$$a = 0.313 + 0.064(R).$$

If these data can be believed, equation 1 can now be expanded, as shown by Briggs and Swanson (1970), to the more complete statement of additivity in reaction time as follows:

$$RT = a + b'(H_c) \tag{1}$$

$$a = c + d(R) \tag{2}$$

so,

$$RT = c + d(R) + b(H_c) \tag{3}$$

In the present case, for the single-task condition

$$RT = 0.313 + 0.064(R) + 0.062(H_c)$$

while for the dual task condition

$$RT = 0.559 + 0.029(R) + 0.062(H_c)$$

The result is incongruous, in part: It would appear that the subjects were faster at response decoding in the dual-task condition (29 msec per response) than in the single-task condition (64 ms c per response), and the faster time is so much faster than that found by Briggs and Swanson (1970) for a single-task situation as to make the present result highly suspect, i.e., that earlier paper reported response decoding times of 84 and 90 msec per response from two different experiments.

We decided, therefore, to perform experiment 7 with more subjects per condition and with more conditions.

EXPERIMENT 7: SPEED VERSUS ACCURACY AND RESPONSE LOAD AS VARIABLES IN A TIME-SHARING TASK.
G. L. Peters, R. P. Fisher and G. E. Briggs.

As indicated heretofore, the outcome of experiment 6 was so at variance with previous research in this and in other programs that a replication of results would be necessary before the data could be believed. The relatively small sample of subjects (6 per condition) might have resulted

in the unexpected interaction by virtue of sampling error. Therefore, sample size was doubled in the present study, and four rather than three independent variables were manipulated: memory load ($M = 1$, 2 and 4), speed versus accuracy (15 versus 5 percent errors) and single versus dual tasks. In essence, experiment 7 represents a combination of experiments 5 and 6.

METHOD

The variables, tasks and procedures were the same as previously described. A new set of subjects participated in the study and there were 12 subjects per group. Groups were defined by the eight combinations of the levels of single versus dual tasks, speed versus accuracy, and response loads of $R = 2$ and $R = 4$.

RESULTS

An analysis of variance of the reaction time data revealed that each of the independent variables was statistically significant ($p < .01$), but no interaction attained significance ($p > .05$). Again, then it does not seem possible to localize the time sharing effect in one or another of the first three stages of the Smith (1968) model of human information processing. However, the analysis for variance dealt only with the reaction-time data and did not consider the accuracy data directly. It is possible to examine the data on speed and accuracy concurrently by use of the additivity analysis first used by Briggs and Blaha (1969) and later extended by Briggs and Swanson (1970).

Recalling equation 1:

$$RT = a + b(H_c) \tag{1}$$

the present data were fit in parallel by this basic statement. Parallel fits are justified on the basis of no statistical interactions among variables. Table 10 summarizes the results of these fits.

Table 10. Parallel Fits (Within Task Conditions) of Equation 1 to the Data of Experiment 7.

Task Condition	Response Load	Speed vs. Accuracy	$RT = a + b(H_c)$
Single	$R = 2$	Accuracy	$RT = 0.423 + 0.072(H_c)$
Single	$R = 2$	Speed	$RT = 0.352 + 0.072(H_c)$
Single	$R = 4$	Accuracy	$RT = 0.557 + 0.072(H_c)$
Single	$R = 4$	Speed	$RT = 0.534 + 0.072(H_c)$
Dual	$R = 2$	Accuracy	$RT = 0.511 + 0.066(H_c)$
Dual	$R = 2$	Speed	$RT = 0.395 + 0.066(H_c)$
Dual	$R = 4$	Accuracy	$RT = 0.636 + 0.066(H_c)$
Dual	$R = 4$	Speed	$RT = 0.578 + 0.066(H_c)$

Table 11. Parallel Fits (Within Task Conditions) of
Equation 2 to the Intercepts of Table 10.

Task Condition	Accuracy	$a = c + d(R)$	Average H_t(fits)
Single	Accuracy	$a = 0.253 + 0.079(H_c)$	1.23
Single	Speed	$a = 0.206 + 0.079(H_c)$	.865
Dual	Accuracy	$a = 0.342 + 0.077(H_c)$	1.255
Dual	Speed	$a = 0.255 + 0.077(H_2)$	.915

As a second step the intercept constants $\underline{a}$ of equation 1 were expressed as a linear function of response load (R)

$$a = c + d(R) \tag{2}$$

as in Briggs and Swanson (1970). Also at this point average information transmitted under each condition was calculated. The average was taken across memory load, response load and subjects. The fits of equation 2 and the average H_c values are listed in table 11. Equation 2 was fit to the single task data in parallel, and separately to the dual task data (also in parallel).

Finally, the intercept constants of equation 2 in table 11 were fit by the following linear function relating $\underline{c}$ to average information transmitted.

$(\overline{H}_t)$:

$$c = e + f(\overline{H}_t) \tag{4}$$

This too follows the additivity procedure utilized by Briggs and Swanson (1970). In fitting equation 4 to the present data it was found that for $\overline{H}_t = 0$, $\underline{c} = 0.070$ provides the smallest errors of prediction. The result for the single-task condition was

$$c = 0.071 + 0.150 \ (\overline{H}_t)$$

and for the dual-taks condition, it was

$$c = 0.068 + 0.214 \ (\overline{H}_t)$$

We may now combine equations 1, 2, and 4 to yield a more complete statement of additivity:

$$RT = e + f(\overline{H}_t) + d(R) + b(H_c) \tag{5}$$

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Following the lead of Briggs and Swanson (1970), the constants of equation 5 may be interpreted as follows: (a) $\underline{f}$ represents the time per bit of accuracy required to sample the encoded test stimulus information in Stage 1, (b) the constant $\underline{e}$ represents the time for all other processing during the initial encoding stage, (c) $\underline{b}$ is the time per binary test to compare, at Stage 2, sampled test stimulus information against memorial representations of possible stimuli, and (d) $\underline{d}$ represents decoding time per response, the Stage 3 process.

When fit to the single-task data, equation 5 yields:

$$RT = 0.071 + 0.150(\bar{\bar{H}}_t) + 0.079(R) + 0.072(H_c)$$

while for the dual task data

$$RT = 0.068 + 0.214(\bar{\bar{H}}_t) + 0.077(R) + 0.066(H_c)$$

In effect, an additivity model has been fit to the data, and in doing so, equation 4 introduced response accuracy into the fit. Thus equation 5 has been used to see in what regard dual-task performance differed from single task performance. Now recall that the analysis of variance indicated task (dual vs. single) was significantly different at $p < .01$; thus, examination of the fits of equation 5 clearly indicates that the constant $\underline{f}$ is the only point in the model which is different for the two task conditions (150 and 214 msec for single and dual tasks, respectively). Since $\underline{f}$ represents the stimulus sampling time according to Briggs and Swanson (1970), a Stage 1 process, it follows that the time sharing effect is localized in that stimulus encoding stage.

This result is intuitively logical, and while converging experiments would be necessary to firm up this conclusion, at present it does appear that the less proficient performance under dual task than under single task conditions is due to the limited capacity of the initial stimulus encoding stage to handle the dual task information. Our search for the locus of the time sharing effect has reached a point of conclusion. In doing so, experiment 7 also indicated that the response decoding times for the dual task groups of experiment 6 were unreasonable, the 77 and 79 msec times per response found in experiment 7 being close to the time of 85 msec noted by Briggs and Swanson (1970).

CONCLUSIONS

1. As noted in earlier research, the input and the output stages of human information processing are slower than the central processing stage of human information processing. The reciprocals of the constants of equation 5 yield estimates of these rates, and these results are listed in table 12. Note that responses per second has been transformed to bits per second, i.e., the $\underline{d}$ term was transformed to a bits scale by noting that there was about $0.\bar{5}$ bits of uncertainty per response in experiment 7.

Table 12. Estimates of Processing Speeds for the Input, Central and Output Stages.

Task Condition	Stage 1 (Encoding)	Stage 2 (Central)	Stage 3 Decoding
Single	6.7 bits/sec.	13.9 bits/sec.	6.3 bits/sec.
Dual	4.7 bits/sec.	15.2 bits/sec.	6.5 bits/sec.

Since Stages 1 and 3 inherently are slower than Stage 2, one should particularly avoid asking the human operator to process information in a situation that will further reduce the speed of either the input or the output stage.

2. Stage 1 or the initial stimulus encoding stage apparently is the locus of the time-sharing effect, and this slowed the speed of this initial processing stage by about 2 bits per second in the present experimental situation. This is a rather hefty penalty required to permit the human operator "to do two things at once."

DUAL-TASK PERFORMANCE AS A FUNCTION OF STIMULUS-RESPONSE COMPATIBILITY,
INPUT COMPLEXITY, AUDITORY NOISE AND DIFFERENTIAL AUGMENTED FEEDBACK

The research reported above in sections III and IV involved a number of
different independent variables each of which was applied to the discrete
reaction time task. The research reported in this section kept the dis-
crete task constant (except in experiment 10) and varied the character-
istics of the continuous tracking task. Within and across the three
experiments we were concerned with the influence of stimulus-response
compatibility, input complexity, auditory noise, and relative emphasis
on the two tasks on performance in a dual task situation.

EXPERIMENT 8: S-R COMPATIBILITY AND INPUT COMPLEXITY ON TIME-SHARING
               PERFORMANCE.
               S. Greenberg, D. Shinar, and G. E. Briggs.

Stimulus-response (S-R) compatibility refers to the relationship of the
directional aspect of controls and displays. Thus if most people pre-
dict that a clockwise rotation of a control will cause some process to
increase, then that directional relationship is identified as a high
level of S-R compatibility. In this example, a low level of S-R com-
patibility would involve just the opposite relationship (a decrease in
the process with a clockwise rotation of the control.). Performance is
generally superior under a high S-R compatibility condition compared
to that under a lower level.

We decided to manipulate S-R compatibility in the tracking task and to
include tracking input complexity as an orthogonal variable. All
subjects performed under the dual task condition, and it was of interest
to see if compatibility and complexity would interact in their influence
on performance on either of the two tasks.

METHOD

The tracking task involved the same (rate) dynamics, the same pursuit
display, and the same spring-centered control stick as was used in
experiments 1 - 7. The input signal was different: the simple input
consisted of a sine wave of 0.05 Hz while the complex input consisted
of the same basic sinusoid plus its first two harmonics all in phase.
In the high S-R compatibility condition the cursor on the display moved
in the same direction as did the control stick, while this was reversed
for the low S-R compatibility condition. (The high S-R compatibility
condition had been used throughout experiments 1-7).

The discrete reaction time task was identical to that used in experiments
4-7: memory loads of $M = 1$, 2, and 4 letters of the alphabet were used
and test stimuli were read to the subject over headphones. The subject

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tracked with the right hand while using the index and middle finger of the left hand to press one of two buttons: match or no-match of the test stimulus to one being held in memory.

Each daily session consisted of two and one-half blocks of trials under each of the three memory load conditions. A block lasted 96 seconds, during which the subject both tracked and responded to the discrete task. Stimuli for the latter occurred every 4 seconds. The initial half block was considered practice as were the entire first two daily sessions; thus only the reaction time and tracking error data from the third and fourth sessions were subjected to analysis. A fifth session was devoted to subject debriefing and pay. The latter involved $1.25 per session.

S-R compatibility and memory load were within-subject variables while input complexity was a between-subject variable. Suitable counter-balancing of the within-subject variables was carried out across subjects. There were 48 subjects in all, 24 per input complexity level. All sub-jects received terminal feedback on their reaction time performance at the end of each block (or half-block) of trials. No feedback was given relative to the tracking task; thus, in experiment 8 the discrete reaction-time task was emphasized over the continuous-tracking task.

RESULTS

An analysis of variance of the reaction time data revealed significant main effect for input complexity ($p < .05$), S-R compatibility, and memory load ($p < .01$ each), but no interaction occurred among these independent variables. An analysis of variance on tracking error revealed signifi-cant main effects for only memory load and for S-R compatibility (both at $p < .01$); again there was no interaction of the variables. It is interesting to note that input complexity did not significantly influence tracking performance, but it did influence the reaction times (reactions under the low complexity condition were slower by 42 msec, on the average, than under the high input complexity condition). This set of results is typical: the Sternberg reaction time task is quite sensitive to inde-pendent variables whereas tracking performance is systematically influ-enced only by more hefty task characteristics. Given the localization of the time sharing effect in the initial stimulus encoding stage, (see experiment 7), it is interesting that input complexity would influ-ence the reaction time data even though that variable was applied to the tracking task.

Table 13 provides average tracking performance under the several condi-tions both while responding to the discrete task (scoring was over the first 2 seconds of each 4-second trial) and while not responding to the discrete task (scoring was over the last 2 seconds of each 4-second trial). Note that even when the subjects were not responding to the discrete task (were not time-sharing), tracking performance showed the same pattern of results as when time-sharing was taking place. Obviously some carry-over effect of the time-sharing situation occurred such that

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tracking performance was influenced by, say, memory load (a variable applied to the discrete task) even when there was nothing to do on the discrete task (except, perhaps, to prepare for the next discrete task stimulus). The performance scores in table 13 are relative tracking error: the absolute tracking error was integrated over the appropriate two-second intervals for each subject as was the input signal; the former then was divided by the latter; therefore, the higher the index, the poorer the tracking performance.

Table 13. Tracking Performance (Relative Absolute Error) in Experiment 8.

Time Sharing	S-R Compatibility	Input Complexity	M1	Memory Load M2	M4
Track only	Low	Low	0.214	0.200	0.233
Track only	Low	High	0.176	0.210	0.228
Track only	High	Low	0.161	0.170	0.188
Track only	High	High	0.132	0.151	0.160
Dual task	Low	Low	0.328	0.333	0.356
Dual task	Low	High	0.272	0.313	0.321
Dual task	High	Low	0.248	0.265	0.335
Dual task	High	High	0.197	0.211	0.239

Table 14 summarizes the reaction-time data. Also listed are least squares fits of equation 1. The fits were carried out in parallel, there being no interaction of memory load with either S-R compatibility of with input complexity.

The results, therefore, are quite straightforward: both the discrete task performance and performance on the tracking task suffered under the low S-R compatibility version of the tracking task compared to that under the high S-R compatibility version. Further, performance on both tasks deteriorated as memory load (on the discrete task) was increased. Thus, each task reflected effects not only from a variable applied directly to that task but also from a variable applied to the other of the two time-shared tasks.

Table 14. Reaction Time Performance (in Seconds) in Experiment 8.

S-R Compatibility	Input Complexity	M1	Memory Load M2	M4	$RT = a + b(H_c)$
Low	Low	0.516	0.582	0.676	$RT = 0.429 + 0.081(H_c)$
Low	High	0.470	0.550	0.650	$RT = 0.395 + 0.081(H_c)$
High	Low	0.493	0.555	0.635	$RT = 0.399 + 0.081(H_c)$
High	High	0.461	0.519	0.627	$RT = 0.374 + 0.081(H_c)$

EXPERIMENT 9: AUGMENTED FEEDBACK, S-R COMPATIBILITY, AND INPUT
COMPLEXITY ON TIME-SHARING PERFORMANCE.
D. Shinar, S. Greenberg, and G. E. Briggs.

We felt that a somewhat different pattern of results might result if the
tracking task was emphasized. To explore this, the discrete and the
tracking tasks were unchanged, except that augmented feedback was
applied to the latter, and the same independent variables were used once
again (S-R compatibility and input complexity on the tracking task and
memory load on the discrete task).

METHOD

A visual display to provide augmented feedback was mounted directly
above the tracking display. This consisted of a small neon bulb (NE51H)
which flashed at a rate of four ignitions per second whenever tracking
error was "on target." The latter was set so that the subject would be
likely to obtain a tracking performance score of about 0.100 under the
easy tracking task (high S-R compatibility) and about 0.150 under the
more difficult tracking task (low S-R compatibility). Thus by making
tracking performance consistent (across memory load levels and input
complexity conditions) it was felt that the discrete performance would
reflect time-sharing effects free of the possible artifacts of differ-
ential emphasis on tracking.

A new set of 48 subjects participated in this experiment. Again input
complexity was a between-subjects variable (with 24 subjects per level)
and both memory load and S-R compatibility were within-subject variables.

RESULTS

The tracking data are summarized in table 15. As can be seen the experi-
menter was successful in using augmented feedback to equalize tracking
performance across memory load and input complexity conditions (within
S-R compatibility level). The data of table 15 may be compared with the
"tracking only" data of experiment 8 (see table 13). Note that we were
successful in increasing the emphasis on the tracking task as in every
cell, the tracking data of experiment 9 are superior (of lower value) to
those of experiment 8 (which emphasized the discrete task).

Table 15. Tracking Performance in Experiment 9.

S-R Compatibility	Input Complexity	Memory Load		
		M1	M2	M4
Low	Low	0.149	0.151	0.150
Low	High	0.146	0.152	0.154
High	Low	0.108	0.099	0.112
High	High	0.103	0.108	0.117

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The data of primary interest are the reaction time averages, and these are summarized in table 16. These results are to be contrasted with those listed in table 14 for experiment 8. Note that in both experiments performance on the discrete task was superior under high to that under low S-R compatibility. However, whereas superior reaction time performance occurred under the <u>high</u> input complexity condition in experiment 8, just the reverse result was obtained in experiment 9. Thus by emphasizing the tracking task over the discrete task, one finds the discrete task performance reflecting more logically both (not just one) of the independent variables imposed upon the tracking task.

Further, comparison of tables 14 and 16 shows that the intercepts of table 16 are significantly higher than those in table 14. Thus emphasizing the tracking task had the effect of lengthening that time constant of equation 1 which reflects encoding plus decoding time. Given the results of experiment 7, we may assume that this relative emphasis was influential primarily in lengthening the stimulus encoding time on the discrete task. The slope constant of table 14 is longer than that in table 16, however this is not a significant difference; therefore, central processing of discrete task information was <u>not</u> influenced by the relative emphasis on tasks, only (presumably) Stage 1 or the initial encoding functions reflected this effect.

Table 16. Reaction Time Performance in Experiment 9.

S-R Compatibility	Input Complexity	Memory Load			$RT = a + b(H_c)$
		M1	M2	M4	
Low	Low	0.619	0.668	0.744	$RT = 0.530 + 0.067(H_c)$
Low	High	0.656	0.721	0.800	$RT = 0.588 + 0.067(H_c)$
High	Low	0.561	0.612	0.689	$RT = 0.483 + 0.067(H_c)$
High	High	0.605	0.658	0.750	$RT = 0.539 + 0.067(H_c)$

EXPERIMENT 10: ON THE LOCUS OF THE S-R COMPATIBILITY EFFECT IN A TIME-SHARING SITUATION.
S. Greenberg, D. Shinar, and G. E. Briggs.

In both experiments 8 and 9 S-R compatibility in the tracking task significantly influenced discrete task performance. That influence can be seen in tables 14 and 16 where lower intercept constants occurred under high S-R compatibility. Now, as indicated earlier, the intercept constant <u>a</u> of equation 1 is interpreted as stimulus encoding <u>plus</u> response decoding time. The present study was designed to see if the S-R compatibility effect could be localized in the stimulus-encoding stage.

This attempt to localize an effect is based on the arguments advanced by Sternberg (1969b) in describing the additive factor methodology. Basically, he indicates that if two variables influence the same stage of

processing, then one should obtain a statistically significant inter-
action of the two variables when the reaction time data are analyzed;
if the two variables influence different stages, then there should be
no interaction as the two variables would have strictly additive
effects upon reaction time. Therefore, to see if S-R compatibility is
localized in Stage 1 (encoding) of the Smith (1968) model of human
information processing, one needs to make that variable orthogonal to
one known to influence Stage 1. If the two interact, this localizes
S-R compatibility in Stage 1; if there is no evidence of an interaction,
then presumably S-R compatibility has a Stage 3 (response decoding)
effect in this time-sharing situation.

Sternberg (1967) has provided evidence that _visual_ noise influences
Stage 1 in a visual display version of the same reaction-time task as
that used with an auditory display in the present program. Therefore,
auditory noise at two levels combined with S-R compatibility, also at
two levels, should permit us to see whether or not the latter will
interact with auditory noise, thereby localizing the effect in either
the input or the output stage.

METHOD

The basic task conditions were the same as those used in experiment 9,
except that only the low input complexity condition was employed, and
there were two levels of auditory noise imposed on the discrete, reaction
time task: low (78 dB) and high (88 dB) levels of the same noise used
earlier in experiments 1, 2 and 3. A new set of 24 subjec's served in
the present study. Both S-R compatibility and auditory noise were within-
subject variables.

Once again the augmented feedback procedure was employed to encourage
equal performance on the _tracking_ task for each of the two auditory
noise levels within each level of S-R compatibility. As in experiment
9, this was done to make it possible to compare low- versus high-noise
effects on the reaction-time task free of any differential performance
on the tracking task.

RESULTS

Table 17 shows that the use of augmented feedback was successful in
equating tracking performance within S-R compatibility level. We may
turn, then, to table 18 and see if there is evidence of an interaction
between S-R compatibility and auditory noise in terms of the reaction
time data.

Table 17:   Tracking Performance in Experiment 10.

S-R Compatibility	Auditory Noise	M1	Memory Load M2	M4
Low	Low	0.166	0.177	0.168
Low	High	0.175	0.162	0.173
High	Low	0.103	0.116	0.121
High	High	0.113	0.133	0.127

Table 18.   Reaction Time Performance in Experiment 10.

Compatibility	Auditory Noise	M1	Memory Load M2	M4	$RT = a + b(H_c)$
Low	Low	0.677	0.746	0.813	$RT = 0.615 + 0.065(H_c)$
Low	High	0.756	0.817	0.847	$RT = 0.676 + 0.065(H_c)$
High	Low	0.657	0.708	0.782	$RT = 0.585 + 0.065(H_c)$
High	High	0.720	0.810	0.890	$RT = 0.676 + 0.065(H_c)$

An analysis of variance of the reaction-time data indicated that memory
load, S-R compatibility, and auditory noise each were significant main
effects, however there was no interaction of variables including the
crucial compatibility by noise interaction. The latter result was dis-
appointing, of course, but the disappointment is mitigated somewhat by
examining the intercept constants $\bar{a}$ listed in table 18. Once again
equation 1 was fit in parallel to the data. This yields the intercept
constants listed in table 19.

Table 19.   Intercept Constants from Table 18.

S-R Compatibility	Noise Level Low	High
Low	0.615	0.676
High	0.585	0.676

From the analysis of variance, S-R compatibility was a significant main
effect; from table 19, performance (as indexed by the intercept constant)
is comparable for both S-R compatibility levels under the high auditory
noise condition (676) msec); therefore the two intercepts listed under
the low auditory noise condition (585 and 615 msec) may be considered to
be significantly different. Thus there is some evidence of an interaction

of S-R compatibility with auditory noise. This, in turn, suggests that S-R compatibility exercised its effect on the stimulus encoding stage of human information processing.

CONCLUSIONS

1. The human operator will indeed respond appropriately when informed which of two concurrent tasks is "more important." Apparently this relative emphasis effect is localized in the input stage of human information processing.

2. Also localized in the input stage is the effect of S-R compatibility in the tracking task.

3. Since the research of section IV, above, has indicated that time-sharing itself is an input stage effect, the results from section V are consistent with the conclusion that the initial stimulus encoding stage is critical in determining the effects, if any, which task variables will have in a dual-task or time-sharing situation.

APPENDIX - The Calculation of Central Processing Uncertainty (H$_c$)

Swanson and Briggs (1969) introduced the use of a Shannon concept to express the uncertainty present at the central or stimulus classification stage of human information processing in the Sternberg task. Specifically, they defined central processing uncertainty or H$_c$ as average uncertainty:

$$H_c = -\Sigma\, p_i \log p_i \tag{6}$$

Now, in the Sternberg task memory load, or the number of items in the positive set in use at a particular time, is the primary determinant of H$_c$: The summation in equation 6 is across all possible outcomes at central processing (p$_i$ being the probability of the ith possible outcome), and memory load determines M of the total of M + 1 outcomes, the additional outcome being a no-match.

Briggs and Swanson (1970) validated the way Swanson and Briggs (1969) had defined the several p$_j$. In their version of the Sternberg methodology, a particular stimulus in the positive set never became an item in the negative set. This is in contrast to both the so-called fixed and the varied set procedures used by Sternberg (1966). Under these conditions a particular item could be in the M = 1 set at one time, then it could be a negative set item, and later it could become a member of the M = 2 or the M = 4 positive set, and so on.

In other words, Briggs and Swanson utilized a truly fixed-set procedure. This enables the subject to treat the negative set as a unitary set, and at the central processing stage the subject need consider the negative set only once in his testing of the test stimulus for membership in the positive or the negative set. Thus, for example, suppose the letters "F" and "O" have been permanently assigned to the M = 2 condition and that the letters "A", "G", "L", and "R" and "Y" have been permanently assigned to the negative set. There are three possible outcomes when a particular test stimulus is presented: (1) match "F", (2) match "O", or (3) match negative set. The usual procedure is to arrange test stimulus sequences such that a match should occur on half the trials, thus p(match "F") = p(match "O") = 0.25, and p(match negative set) = .50. In this case, then, H$_c$ = 0.5 + 0.5 + 0.5 = 1.5 bits. For memory loads of M = 1 and M = 4, H$_c$ = 1.0 and 2.0 bits, respectively.

The above model for calculating H$_c$ holds only when the subject experiences a truly fixed set procedure and only when the size of the negative set exceeds the size of the positive set. Thus, when the size of the negative set equals the size of the positive set, as it did in the first two experiments reported above, then the subject apparently treats each item in both the positive and the negative sets as individual stimuli, i.e., he does not treat the negative set as a class. It follows, then, that for the M = 2 condition since each of the two positive set stimuli

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and each of the two negative set stimuli occurred with p = 0.25, H_c = 0.5 + 0.5 + 0.5 + 0.5 = 2.0 bits. For M = 1 each stimulus occurred with p = 0.5, so H_c = 1.0 bits, and for M = 4 each positive and each negative set stimulus was equally likely (p = 0.125), and so H_c = 3.0 bits.

Now there is evidence (Johnsen, 1971) that under the Sternberg (1966) so-called fixed set procedure the subject makes a series of tests. A straightforward model, which provides adequate fits to the data, is based on the assumption that each test involves a comparison of the encoded test stimulus against both a positive set stimulus and the features of a subset of the negative set. It is assumed that such testing is exhaustive, so under M = 2 a first test involves p(positive set stimulus "F") = 0.25 vs. p(negative set) = 0.25 and a second test involves p(positive set stimulus "O") = 0.25 versus p(negative set) = 0.25, therefore H_c = 0.5 + 0.5 + 0.5 + 0.5 = 2.0 bits, since only one test is required under M = 1, H_c = 1.0 bit. The M = 4 condition involves four tests: each positive stimulus occurs with p = 0.125, and p(negative subset) = 0.125 for each test. Thus H_c = 4 (0.375 + 0.375) = 3.0 bits.

Experiments 4 through 10 employed the Sternberg (1966) "fixed" set procedure, and so H_c = 1.0, 2.0 and 3.0 bits were the scale values used to fit equation 1 to those data. The H_c values 1.0, 2.0 and 3.0 bits also were utilized for fits of equation 1 to the data of experiments 1 through 2. Experiment 3 utilized a large and permanently fixed negative set, thus as indicated above, Hc = 1.0, 1.5 and 2.0 for memory load levels M = 1, 2 and 4, respectively.

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